ESD-TR-70-202

INFORMATION PROCESSING TECHNIQUES FOR NETWORKING AND GRAPHICS RESEARCH

Thomas E. Cheatham, Jr.

June 1970

DIRECTORATE OF SYSTEMS DESIGN AND DEVELOPMENT
HQ ELECTRONIC SYSTEMS DIVISION (AFSC)
L. G. Hanscom Field, Bedford, Massachusetts 01730

Sponsored by: Advanced Research Projects Agency
Washington, D. C. 20301

ARPA Order No. 952

(Prepared under Contract No. F19628-68-C-0379 by Harvard University, Cambridge, Massachusetts.)

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FOREWORD

This report summarizes work accomplished under Contract F19628-68-C-0379 during the period 1 July 1968 through 30 June 1969. This contract is concerned with research on computer graphics and computer networking. The report describes work directed to development of new insights into the creation, analysis and presentation of information in man-computer systems.

Professor Thomas E. Cheatham, Jr. was the principal investigator for the contract. Dr. Lawrence G. Roberts was the ARPA director, Dr. Sylvia R. Mayer was the ARPA agent at Electronic Systems Division, Air Force Systems Command.

This technical report has been reviewed and is approved.

Sylvia R. Mayer

SYLVIA R. MAYER
Research Psychologist
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ABSTRACT

Work on the PDP-1 facility at Harvard has proceeded over a broad front for the past year FY 69; projects range from exploration of efficient display technology to computer art and include projects for computer assisted organic molecular synthesis, stereo and color display, character recognition, and tree manipulation. This report briefly summarizes the major accomplishments over the year and references the various published papers and technical reports which contain the detailed reports.

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SECTION I

TECHNICAL SUMMARY

This report describes the results of the program of research carried out at Harvard University utilizing the PDP-1-based computer graphics facility during the past year (FY69). This program has involved the investigation, design, implementation, and experimentation with a user input/output interface which permits input via a RAND tablet and coordinated output via four relatively high speed point-plotting cathode ray tube output devices. In addition, input/output via a large variety of switches, levers, audio, converter, three-dimensional sensors, and so on is provided for.

There have been three primary areas of activity during the course of the past year; we might briefly characterize these as (1) development of mathematical and physical (i.e., hardware) techniques for graphical display, (2) development of an appropriate man-machine interface which provides a user with a sophisticated input/output facility appropriately tailored to his particular problem area, and (3) development of and experimentation with specific application programs to permit evaluation of the man-machine interface.

The projects undertaken under the first area of activity have included the development of mathematical techniques for homogeneous coordinate representations and display, technique for projections of three dimensional curves and surfaces, technique for rapid generation of two-dimensional curves, algorithms for hidden line elimination in a half-tone three-dimensional perspective picture, and computation of Fourier series approximations to curves. In several cases hardware techniques to speed output have been proposed as a result of these mathematical investigations. In addition, work has been done in developing techniques for color and stereoscoptic display as well as for sensing and input of coordinates in three dimensions.

In the second area, the development of man-machine interfaces, most of the work has been in the development of a variety of system programs which implement the mathematical techniques developed in the first area and, in general, provide a set of "program packages" which are used by the several application programs developed in the third area. These "program packages" provide facilities for windowing (i.e., "clipping" those portions of a large display which are not to be "seen" on the output device at a given time), facilities for recognition and display of standard and non-standard characters, a hard-copy output facility, an overlay and drum utility package, and a number of other small utility programs.

In the third area, that of specific application programs utilizing a sophisticated man-machine interface, the most important project which has been on-going is that for the computer-assisted design of complex organic molecules. During the year this project has resulted in an operational (but prototype) system which can actually be used by organic chemists not familiar with computer operation or computer programming. A number of other projects including a system for input/output of non-standard characters, a system which permits input of music in standard notation and can play the music for output, a cryptographic study of the Voynich Manuscript, and numerous other small applications. These various projects have demonstrated unequivocally the value of a good man-machine interface in permitting a non-computer specialist to solve complex and important problems.

SECTION II

INTRODUCTION

This report describes the results of the program of research carried out at Harvard University utilizing the PDP-1-based computer graphics facility during the past year (FY69). This program has involved the investigation, design, implementation, and experimentation with a user input/output interface which permits input via a RAND tablet and coordinated output via four relatively high speed point-plotting cathode ray tube output devices. In addition, input/output via a large variety of switches, levers, audio, converter, three-dimensional sensors, and so on is provided for.

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Each of the major projects undertaken under this contract have been reported upon in some detail in various reports and papers. The section titled BIBLIOGRAPHY lists these. In this report we will thus merely comment briefly on each project and refer the interested reader to the reports and papers cited for further details. The projects reported upon are the following:

1. "Three-Dimensional Curves and Surfaces for Rapid Computer"
   Theodore M. P. Lee

2. "Iterative Techniques for Computer Graphics"
   Dan Cohen

3. "Computer-Assisted Design of Complex Organic Molecular Syntheses"
   E. J. Corey and W. Todd Wipke

4. "PDP-1 Hard Copy Facility SPLOT"
   W. Todd Wipke and Scott Stekette

5. "Music 3"
   William B. Barker

6. "A Tree Manipulator"
   William B. Barker

7. "Curve Fitting"
   Arthur S. Priver

8. "The Synchronous Wheel"
Richard L. Land

9. "A Computer Graphics System for Non-Standard Characters"
Susumu Kuno, Tamotsu Makaii, Sheila Duncan

10. "The Voynich Manuscript"
Jeffrey Krischer

11. "A Class of Surfaces for Computer Display"
Theodore M. P. Lee

12. "A Character Recognizer"
Alan Evans

13. "Fast Drawing of Curves for Computer Display"
Dan Cohen and Theodore M. P. Lee

Discussions of these projects are found in Section III.

SECTION III

TECHNICAL DISCUSSIONS

3.1 Three Dimensional Curves and Surfaces

T. M. P. Lee

In order to document the research for his Ph.D. thesis, Mr. Lee has used the PDP-1 facilities to produce a 12 minute film "Rational Bi-Cubic Surfaces." The purpose of his research was to investigate the possible application of this particular technique for the rapid generation of pictures of three-dimensional curved objects. The film was necessary to show real-time motion and transformation of surfaces, since the PDP-1/340 combination is not fast enough to be able to give the illusion of continuous motion.

This research is reported in detail as ESD-TR-69-189 (Thesis), "Three Dimensional Curves and Surfaces for Rapid Computer Display," May 1969, under this contract.

Following is an abstract of this work:

Rational parametric polynomial functions of second degree or higher provide a class of curves including all conic sections. They can be generated by an iterative process easily implemented in software or hardware. The numerical accuracy of the process is analyzed. Algorithms for the specification, display, and modification of the curve are presented. Such curves are represented in a homogeneous coordinate formulation convenient for computer applications.

Three dimensional surfaces composed for such curves are similarly convenient to use. Without recourse to trigonometric functions such classical surfaces as spheres and toroids can be readily described. The ease with which translation, rotation and projective transformations can be applied is exhibited. In particular, we do not perform such transformations on the points of the surface to be displayed -- upwards of several thousand -- but rather upon the rather small set of numbers in a $4 \times 4 \times 4$ tensor that represents the surface.

These surfaces are intended to be used in an interactive, free form computer-aided design system. In this direction we discuss the enforcing of continuity conditions and possible data structures for representing the surfaces.

3.2 Iterative Techniques for Computer Graphics
D. Cohen

In completing work on his Ph.D. thesis Dr. Cohen has been using the PDP-1 facilities to investigate efficient ways of doing a set of interesting problems in computer graphics. The problems he has examined include, among others, two-dimensional curve generations, eliminating hidden lines in a half-time three-dimensional perspective picture, simulations of radar scanning, and simulation of parallel processing networks. In general, the result of his work has been to isolate the critical areas of the topics under discussion and to find computationally efficient means to solve the problems in these areas, the efficiency being achieved through iterative methods.

This work is being reported in full detail under technical report ESD-TR-69-193 (Thesis), "Incremental Methods for Computer Graphics," May 1969, issued under this contract.

Following is an abstract of this work:

This dissertation is concerned with incremental methods for Computer Graphics. The incremental approach is applicable to many other fields and the computational problems as well, but I decided to concentrate on its applications to Computer Graphics only.

After a short introduction (Chapter I) I discuss, in Chapter II, the problem of curve generation and display. I start by walking in the well-known paths of representing two-dimensional curves as perspective projections of curves in spaces of higher degree, then I apply my incremental approach and get a fast method for generating curves. My incremental method has a unique way of predicting the cumulative error, which results from the interations involved, and correcting for it.

In addition to this technique for curve generation I show, in Chapter III, my method for generating two dimensional curves, the linear differences method. Past attempts to attack this problem (even in a less general form) were set back by mathematical difficulties. My approach, which is mathematically more general, leads to a complete resolution of the mathematical problems which arise from this family of curves.

Next, in Chapter IV, I present my contributions to the hidden line elimination problem. My incremental approach to this problem is typified by a simplicity which sharply contrasts with most of the known techniques in this field. My approach is applied to the "Warnock algorithm" which is discussed in (IV.2), changing it into a completely incremental algorithm.

In Chapter V, I discuss a method for half-tone image production. The main idea was first suggested by Professor D. Evans of the University of Utah. It is generalized so that it may be used for

coordinates systems, other than Cartesian. I also demonstrate the application of this generalized method to polar coordinates, taking advantage of the peculiarities of this coordinate system.

In the last chapter, Chapter VI, an incremental technique for a very fast detection and computation of line intersections is presented. This problem is very important in many applications dealing with three dimensional objects. I estimate that my method is faster than any existing method by, at least, an order of magnitude. This method is based on using the "Sutherland interpolator," a device which was invented here at Harvard University as a part of the three dimensional graphic project.

3.3 Computer-Assisted Design of Complex Organic Molecular Syntheses
E. J. Corey and W. T. Wipke

The work on this project has proceeded beyond the stage of a feasibility study to the point of becoming a useful tool for the chemists working on the project.

During the summer of 1969 a movie was made documenting the performance of the latest version of OCSS, OCSS 5. Many chemical heuristics are being implemented to give OCSS 5 considerably more power as an artificial intelligence program. Finally, the display capability of OCSS 5 will be human engineered to a greater degree so that the chemist can observe many chemical structures simultaneously.

The current progress of OCSS is described in the article "Computer-Assisted Design of Complex Molecular Synthesis," by E. J. Corey and W. Todd Wipke appearing in SCIENCE.

3.4 SPLOT, A PDP-1 Hard Copy Facility
W. T. Wipke and Scott Stekette

A software package called SPLOT has been developed to permit use of the CALCOMP plotter overlapped with main program execution. This package includes facilities which make use of the plotter simple when creating pictures. The plotting is initiated when SPLOT is called and control is then returned to the user while plotting continues. In this way complete overlap of the IO and computation occurs. When the plot is complete the plotter stops.

The system is specifically designed so that the user program creates a picture display file in a dynamic storage block. The user gives ownership of the block to SPLOT and creates a new picture display file to replace the one just given away. SPLOT begins plotting it if it is not already busy, and if it is busy it adds the picture to its que. When it finishes a picture, it clears bit 0 of the word

preceding the picture block which is equivalent to erasing an array. The block is now free storage. An added flexibility is that SPLOT is given the names of two blocks. One is the picture to be plotted and the other is either a subpicture or a dummy. Thus the picture may contain a subroutine which will be erased when the picture is erased. Of course the picture may contain any number of subroutines but only one may be erased with the picture.

3.5 MUSIC 3

William B. Barker

This program permits the user to input music in standard notation, using the RAND tablet and the scopes. When told to do so, the program plays the music over a speaker.

To use the program, one moves the pen so the tracking cross lies on top of the note of the desired duration at the top of the screen. By pressing down on the pen and then letting up again, one picks up the note, which then replaces the cross, and tracks the pen. The note is then moved to the desired location on the scale, and put down, by again pressing down and releasing the pen.

Accidentals may be inserted by putting the symbol on the staff before getting the associated note. The last note, with its accidental, if any, may be deleted by pressing the "KILL" button. The music may be played by pressing the "PLAY" button. When the playing is complete, control is returned to the user, who may then add and delete notes.

Because of the simplicity of use of this program, it may be readily used by people with no knowledge of computers. Because of the ability to add a single note, hear the complete piece, change that note or others, and hear immediately the effect of the change, the program lends itself both to teaching the musically naive, and to aiding in the work of the serious musician. An additional benefit is the ability to obtain hard copy of the composed music from the CALCOMP plotter.

3.6 A Tree Manipulator

William B. Barker

This program was written to provide a means to communicate with a transformational grammar program on the SDS-940, so that the input and output trees could be viewed as two-dimensional trees, rather than as the LISP linear parenthesized string.

The program has two basic modes of operation: an edit mode and a control mode. In the edit mode, one may add, delete, or move nodes


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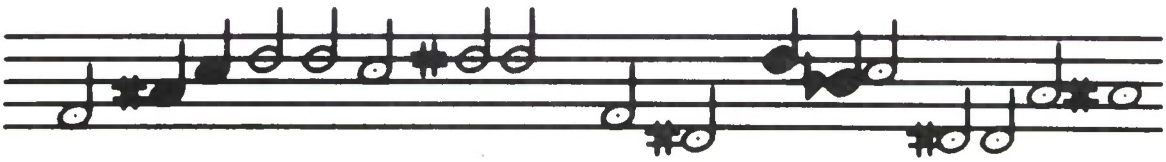

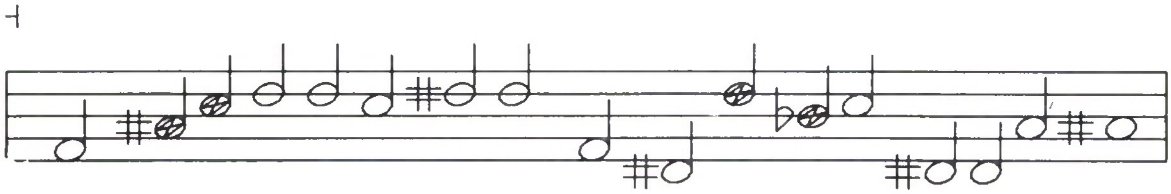

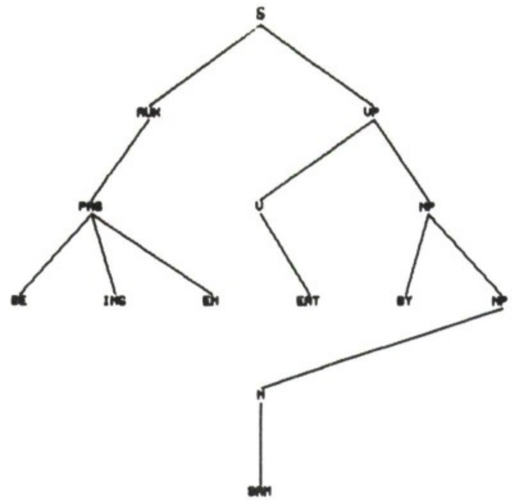
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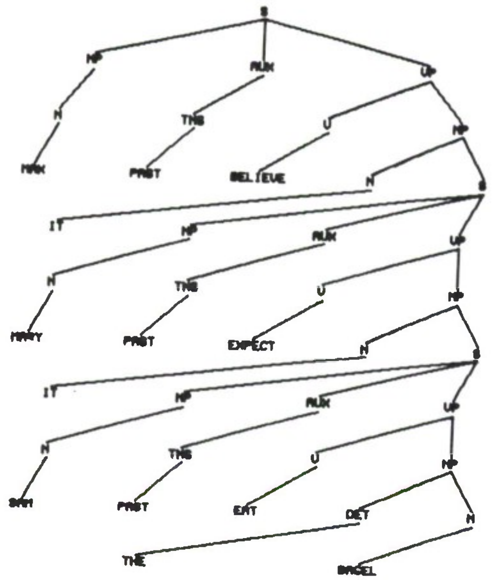
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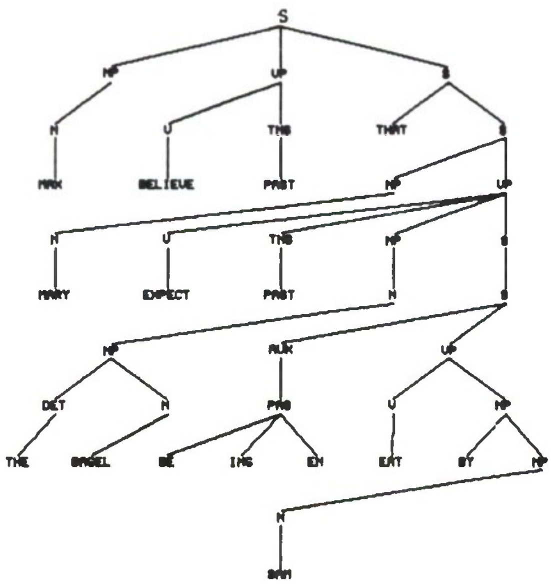
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or groups of nodes to the basic tree structure. A group of commonly used nodes is provided at the bottom of the screen. If one of these is desired, the tracking cross is moved to the desired word, and the pen is pressed and released. The word itself now replaces the cross, and is moved to the desired location on the screen. The pen is again pressed and released. Now the program asks what node is to be the father of the new node by replacing the word just put down with the word "FATHER". This word tracks the pen, and should be moved to the node which is to be the father. Once again, the pen is pressed and released, and the program generates a new display, with the new node in place. All other nodes are shifted to recenter the display.

If a word other than one of the words displayed at the bottom of the screen is desired, the word "TYPE" should be pressed. The program then waits for the operator to type in the desired word, terminated with a period. This word then replaces the tracking cross, and the program proceeds exactly as above.

If it is desired to copy some sub-tree to a new location on the tree, the father node of the sub-tree is touched instead of one of the words at the bottom of the screen. The word "NODE" then replaces the tracking cross, and the insertion proceeds as above, except that the node and all its progeny are inserted instead of a single word.

To delete a node or subtree, one simply touches the "DELETE" button in the upper left corner, then the node. A new display is generated with that node and all its progeny deleted.

When the editing is complete, one presses the "ESC" button and returns to the control mode. If the "SEND" button is now pressed, the tree is linearized to LISP notation and transmitted to the 940.

If it is desired to see a subtree in more detail, one may press any of the four digits under "Display on", to indicate which of the four scopes one wishes the tree displayed on, and then touch a node of the tree. That node and its progeny will then be displayed on the indicated scope. One may then move the tracking cross and control to that or another scope by touching the relevant digit under "Switch to".

Hard copy may be obtained by pressing the "PLOT" button. This initiates drawing of the displayed structure from the scope where "PLOT" was pressed onto the CALCOMP plotter. Several calls to PLOT may be stacked, from the same or different scopes. In this case, the plotter will draw the pictures from the indicated scopes as they were at the time when the call was made, in the order in which the calls were made, even though the structure on the scope may have changed in the interim.

The program also provides the facility for the 940 program to ask the user one of a set of questions. The user responds by pressing the "YES" or the "NO" button. He can consider the tree before

responding by pressing the "WAIT" button, which displays the tree again, but leaves the answer buttons active.

Using this facility, the 940 routine asks the user whether he wishes to see the transformed version of the tree before and after the application of each transformation. If the answer is yes, the 940 sends its LISP linearized version of the tree, and the PDP-1 program converts this to a two-dimensional tree, which it displays on scope 1.

The previous contents of the other scopes are not lost, however, and can thus hold previous versions of the tree. If it is desired to bring them up to date with the latest version of the tree, the "UPDATE" button is pressed.

This program effectively solves the problem of communicating with an essentially tree-oriented program, such as the 940 program with which it was designed to work.

3.7 Curve Fitting

Arthur S. Priver

This past year programs have been written for fitting least-squares Fourier Series to given sets of data points. This work is in connection with data smoothing. As one method of experimenting with this smoothing technique a set of coefficients of a Fourier Series is read and the series is evaluated at a set of points. Then normally distributed random noise with specified mean and variance is added to each point.

Various degree Fourier series are then fitted to this new data to see how well the original coefficients can be recovered. Three curves at a time are displayed on the screen which are labeled by the degree of the series that they represent. This work will be tied together with earlier work on least-squares polynomials and spline fitting in a generalized curve and data analysis system.

A fast Fourier Transform Fortran program was adapted for the PDP-1 and tests were run comparing the FFT with the method which had been the best one - Goertzel's algorithm. As expected, a two minute run was reduced to about ten seconds.

An extension of work of Sutherland and Wipke on a text formatting system has been done. The new version, TEXT 2, takes an input file from the drum, puts a data on the first page, numbers pages, formats the text, inserts spacing if desired for tabbing, single, double, or triple spaces, and does various other useful things for producing output documents. The various options are listed on the 340 scopes when the program is started.

3.8 The Synchronous Wheel
R. I. Land

The synchronous wheel is a simple attachment which can make a conventional display system capable of producing colored stereo pictures in real time. The stereo color display uses a small filter disk held just in front of each eye separately. Rotation of the disk is synchronized with the presentation of the stereo pairs and color-spearated images.

The basic system consists of a filter wheel whose six segments are successively: red, opaque, green, opaque, blue, and opaque. The computer display tube used has a white phosphor which is reasonably balanced in red, green, and blue output and has fast decay. The red right-eye image is drawn while the right eye is looking through the red filter segment; it is followed by the blue left-eye image which is drawn while the left eye is looking through the blue segment, etc. The rotation speed of the filter is sufficiently fast to offer negligible flicker of the integrated image, but slow enough so the phosphor output from one image has decayed before the color wheel reaches its next position.

We have experimented with our device using pictures produced with a Digital Equipment Corporation PDP-1 computer using type 340 display hardware. Within a display area 25 cm square, image points can be positioned in two dimensions to within 0.3 mm. Control of the relative brightness of the color separation images is provided both by repetition of particular images and a limited range of intensity control.

Synchronous filter wheel associated graphic display work during the recent period involved considerable publication of results and two new developments. Real time 3-D drawing was programmed using the RAND Tablet (x,y) and Joy Stick (z) for input and the half opaque filter wheel for viewing the fast scope display. Display files about 15 ms long can satisfactorily be drawn in this system. Eye sensitivity detects the small persistent phosphorous decay using shortened display from the 25 ms 1/2 wheel cycle.

Designs for a 3-D pen system are complete and fabrication of the units required is half complete. The technique suggested by Al Brenner uses a spark gap pen which launches a shock wave at t_o, and three plane microphones (12" square) to detect first arrival of the shock. Counter started at t_o, then one stopped giving values proportional to x, y, and z, in computable format for I/O input.

Perceptual experiments uniquely available with the filter wheel stereo color displays continue. An invited article "Computer Art" will appear in the fall issue of Leonardo mentioning some work on the PDP-1. A paper "Computer Aided Theatrical Production" was given at the annual meeting of the U. S. Institute for Theatre Technology and will be submitted for the Journal shortly; this also incorporates a demonstration of techniques proposed using the PDP-1. For a Computers

and Humanities symposium a survey paper was prepared briefly touching on both graphics and pattern recognition work generally with a few examples drawn from current work here.

This rotating filter device has proven to offer a considerable advance in the unambiguous display of real-time computer output. It may also offer an interesting tool for examination of various phenomena of vision. The simplicity, low cost, and adaptability to existing display systems recommends this device as a technique for real-time, stereo-viewing of full color displays.

3.9 A Computer Graphics System for Non-Standard Characters
Susumu Kuno, Tamotsu Mukaii, Sheila Duncan

The year's work has resulted in new developments on a system which was originally designed as an answer to the need for inputting and outputting Chinese characters for automatic translation processing. A thorough description of the organization of the original system may be found in the Communications of the ACM, Vol. 11, Number 9, September 1968, "Graphical Input-Output of Non-Standard Characters". The system has since been expanded to include other non-standard orthographies as well. The system used a PDP-1 computer with cathode-ray tube display scopes and a RAND tablet as input devices, and a Stromberg-Carlson's 4020 recorder as an output device. Each character is internally represented by pairs of coordinates. Each pair corresponds to the beginning and end point of each of the straight lines which constitute the character on the 16 x 16 grid which is standard for all of the characters in the repertoire of the system.

With the use of this system, a text may be encoded in any orthography or combinations thereof. The repertoire of the system currently includes 8,000 Chinese characters, all Japanese syllabic characters, all Korean syllabic characters, the Tamil syllabic characters, the Pahlavic, Hebrew, and English alphabets, and a set of mathematical symbols.

3.10 Voynich Manuscript
J. Krischer

Mr. Krischer has been using the non-standard character input programs developed by Kuno, Duncan, *et al*. on a most interesting project. It concerns a 16th century manuscript, attributed to Francis Bacon, which has never been translated. The chief difficulty is that it is written in a fictitious alphabet in an unknown language. Krischer has used the graphic input to create a typewriter-like input for this alphabet in order that it may be studied by standard cryptographic and linguistic techniques. The results of this project are contained in a term paper "The Voynich Manuscript" by J. Krischer, submitted for Linguistics 205 during the Spring Term 1969. The preface from that term project is as follows:

The Voynich Manuscript, a codex of unknown origin and unknown content, has been studied by a small number of people since its discovery in 1912 by Wilfred Voynich, a rare book dealer. Three of the group of investigators independently published decipherments of the text. However, following each publication, there has appeared in the literature a refutation, and generally the solutions are either unextendable or make use of unconventional abbreviations. The secrets of the manuscript remain undiscovered.

This paper attempts to gather together the known history of the manuscript and to evaluate the proposed solutions by Professor William Newbold, Joseph Freely, and Brigadier John Tiltman. The manuscript is divided into four sections which are defined by groupings of drawings (botanical, astrological, biological, and pharmaceutical) and a fifth section of text without drawings. Section three of this paper contains a survey of the attempts made to identify the pictures found in each section and to relate them to the text.

Part II contains a description of the techniques employed by the author to try to correlate the statistical behavior of the text with the characteristics of known languages. In particular, the style of a language is defined as the set of characteristics of that language which manifest themselves in any sufficiently large body of text which satisfies the grammatical and syntactical constraints of that language. A measure of these characteristics should be relatively independent of the amount of text being analyzed. Such a measure is the "characteristic" K proposed by G. Udny Yule.

Yule's characteristic is based upon an analysis of the words which comprise a body of text. The characteristic is a measure of the diversity with which one selects words in writing in a particular language. If one were to form a distribution of the number of words used in a body of text and how often each word is used, then for a given sample of text, it is possible to group the words according to the frequency with which they are used (frequency of occurrence). This concept of characterizing a body of text by the distribution of the frequency with which words are used in the text has been used to compare texts of unknown or disputed authorship and aid in the identification of the true author [15]. The application of the characteristic within the framework of this paper is to aid in the identification of the language which serves as the base for the script of the Voynich Manuscript.

An additional part of the statistical analysis of the manuscript is based upon a more narrow view, that is, considering the script as a sequence of individual letters and ignoring the word groupings. One can consider the sequence as being the output of a finite-state Markov process and calculate the transition matrix and distribution of state variables which would produce such a string. This analysis is done in Section 2.3. This type of analysis "breaks down" each letter into its particular function in a language. For example, a certain letter might be used quite frequently as a final letter, that is, the letter

which most often preceeds a word space, in a language. If, in the same analysis of the letters of the manuscript, and the letters of another language, two letters produced similar results, then one would have some justification in making a correspondence between those two letters; both demonstrating the same use in language. In this way Markow analysis provides clues to the language of the manuscript.

It is hoped that this paper will provide a strong platform from which to undertake an analysis of the script by the statistical techniques described above. This would be the first application of such techniques to language identification, and would be a significant application of computer technology to the humanities.

3.11 A Class of Surfaces for Computer Display

Theodore M. P. Lee

The following is an abstract of a paper describing the work in this area:

This paper describes a class of three-dimensional surfaces well-suited to computer display. The mathematical description of the surface is a homogeneous coordinate formulation of Coon's surfaces providing sufficient degrees of freedom to make them attractive for on-line shape design. Without recourse to trigonometric functions such classical surfaces as spheres and toroids are readily described.

The use of iterative computation techniques to provide rapid response is discussed. The properties of the boundary curves and interior contour curves (all rational parametric cubics) are examined. The ease with which translation, rotation and projection transformations can be applied is exhibited. Simple continuity constraints are studied.

3.12 Character Recognizer

Alan Evans

The user may define characters A-Z and 0-9 in one mode and have single characters recognized in another mode. This is not a real-time recognizer. There are buttons for defining, recognizing, and erasing characters. Scope code is added and deleted from the display file without stopping the scope processor, and this necessitates some tricky manipulations. The scope program displays large characters drawn with vectors. Count is made of the number of times the pen goes down as the user is drawing, for a measure of the number of strokes. A grid (5 x 5 here) is laid over the user's character. Every block through which the character passes is noted by a block number counter. The progression of the character from block to block is recorded. The final decision involves finding a best match in strokes, number of blocks, and progression.

3.13 Fast Drawing of Curves for Computer Display

Dan Cohen and Theodore M. P. Lee

The following is an abstract of a paper describing the work in this area:

Recent advances in computer display hardware have been concerned with achieving the ability to rapidly draw curves in two or three dimensions. Rational parametric polynomial functions of second degree or higher provide a class of curves including all conic sections. Such curves can be generated by an iterative process easily implemented in hardware or software. The mathematics for specifying, transforming and manipulating the curve are formulated in matrix algebra. In particular, transformations exist which alter the rate of display of the curve without changing its shape. Curves may be sectioned into smaller potions or expanded into larger continuations. The specific properties of rational parametric cubic polynomials are discussed in detail.

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13. ABSTRACT

Work on the PDP-1 facility at Harvard has proceeded over a broad front for the past year FY 69; projects range from exploration of efficient display technology to computer art and include projects for computer assisted organic molecular synthesis, stereo and color display, character recognition, and tree manipulation. This report briefly summarizes the major accomplishments over the year and references the various published papers and technical reports which contain the detailed reports.

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